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ABSTRACT

The study examined the electrophysiologic organization of cognitive function in 12 normally achieving righthanded boys and 12 reading disabled third and sixth grade boys. Ss were administered reading comprehension and spelling recognition subtests from the Peabody Individual Achievement Test. Electroencephalography (EEG) scores were recorded for each task. Data suggested the existence of a developmental component in slow wave activity of the EEG as the Ss performed cognitive tasks. Further, differences existed between normal and LD Ss which may be attributed to a developmental component in the EEG. (CL)

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Developmental Component in Brain Electrical Activity of Normal and Learning Disabled Boys

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Running Head: A Developmental Component

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Abstract

The behavioral orientation in the American educational system has been pervasive over the past 100 years. Attempts to address the brain/behavior relationship from the educators perspective have been rare until recent years. Understanding the physiological substrates to the diversity of learner characteristics will enhance our knowledge of how learning occurs. The brain and its functional organization develop throughout childhood and adolescence. Assessment of that process has traditionally been accomplished by performance related methodologies. Such techniques may be nicely supplemented by objective assessment of the functional development of the brain. Thus, the more complete brain/behavior picture will emerge. The present investigation demonstrates a developmental component in slow-wave EEG activity as normal and learning disabled boys (3rd and 6th grade) engage two verbally oriented subtests from the Peabody Individual Achievement Test. Most importantly, this single parameter supports a dvelopmental component in learning disabilities, reinforcing continued investigation of electrophysiological substrates in learning and a potential for future clinical application.

Introduction: The Educators Perspective

The phenomenon of learning is the single most important function in living organisms, both directing and organizing behavior in order for individual and species survival (Hebb, 1949). Within that context, the understanding of how learning occurs is a significant pursuit for mankind. The knowledge that the human species is vested with the potential for several distinct types of brain organization leads us to investigate the neurological substrates in the development of cognitive organization (Levy, 1977). In addition, those differences should direct our attention towards more effectively planning and executing instructional strategies. The necessity to conform to one expected mode of learning ought not be one towards which we direct our energies; rather, the diversity of human learning characteristics should lead us to provide a variety of instructional modes for the most productive learning among all individuals.

The traditional model in teacher preparation has most commonly stressed a foundation in the methods of teaching various subject areas, an understanding of the principles of child development, educational psychology, and the philosophy of teaching. Coursework pertaining to the brain/behavior relationship has not been considered relevant to the needs of the teaching profession,

although the brain and central nervous system are the principal organs involved in learning (Gaddes, 1980). The model reflects the continued acceptance of the behavioral psychology developed by John B. Watson in the early 1920's and its reliance upon observable behavioral data in research methodology. More recently, the Gestalt school developed a point of view more dependent upon a within-child model that accepts subjective data to explain within-subject psychological variables. Many frustrated educators have found themselves somewhere between those two diverging points of view.

Not until the 1960's, with the application of neuropsychological findings to learning, was there an opportunity for psychologists and educators to observe and demonstrate neuro-physiological correlates of behavior in explaining within-subject variables (Doehring, Trites, Patel, and Fiedorowicz, 1981). This allowed for the reduction of the speculative component in accepting subjective data. At the same time, special educators began to apply neuropsychological insights towards understanding learning disabilities (Benton, 1962; Benton & Pearl, 1978; Kephart, 1964; Kirk & Bateman, 1962; Reitan, 1966). A much clearer understanding of children with various learning problems could be possible by applying neuropsychological data in comprehending the substrates of their overt behavior. There must come a point where differences between those collecting data from the behavioral perspective and

those approaching their research from a brain-oriented perspective must be reconciled (Duffy, 1981). A current direction in educational research is to address that issue by investigating the brain/behavior relationship through the tools made available in clinical neurophysiology.

Learning Disorders

In addition to the general reconciliation of the two typically diverging viewpoints of the brain/behavior dichotomy, the orverriding issue in learning-disorder research is to operationally define the target population. The concept of "learning disorder" has been part of the jargon of educators for perhaps 20 years (Kessler, 1980), yet educators have been concerned with problem learners for far longer (Hinshelwood, 1907, 1917; Orton, 1937). In a general sense, learning disorders encompass an individual's inability to learn based on a number of factors that include mental deficiency, sensory handicap, emotional disturbance, and noxious environmental influences (Benton, 1975). However, the more specific explanation interprets reading disability as not attributable to specific causal variables. By far the most prevalent manifestation of learning disorder is reading disability, which characterizes the major portion of those school-aged children identified to receive special instructional intervention (Gaddes, 1980). Because it is a failure in acquiring a basic school skill, the most widely used

defining characteristics are stated in a negative manner. Learning disability is typically described as a child's failure to learn to read although possessing adequate intelligence, adequate vision and hearing, sufficient oral language skills to form a solid learning-to-read base, and beginning school with normal motivation to learn to read (Benton, 1975). In simple terms, it can be referred to as an "unexpected reading failure" (Symmes & Rapoport, 1972).

Most striking regarding the prevalence of reading disabiliity is the number of males identified as being disabled readers (Belmont, 1980). The significance of the sex difference was nicely documented by Lovell, Shapton, and Warren (1964) when they reported their findings from a large scale survey of reading ability in 2,669 English school children. When the reading disability is "specific" (i.e., not attributed to intellectual factors), the relative frequency of reading failure in children with IQs of 90 or above is 11% for boys and 3% for girls. Even more dramatic is the frequency of reading failure related to sex and age, in which the ratio of males to females in seven and eight year-olds is 5% to 1.4%, and in the nine to 10 year-old group ranges from 5% to 0%.

Related to the high incidence of males represented in the reading disabled population is the genetic factor. The genetic analysis of behavior attempts to explain the genetic component of behavioral differences. Within the context of reading disorders,

the high propensity of male involvement leads us to assume a familial tendency for expression of the trait. Perhaps the genetic component may provide the necessary unifying context through which the brain, behavior problem might be addressed (Childs, Finucci, & Preston, 1978). In fact, the term "congenital word blindness" was used for many years as the descriptor for reading disability or dyslexia.

The most frequently cited generic definition of reading disability related to performance characteristics is reading skill retardation of 2 years, explainable by intellectual deficit. Such a general descriptor of reading disability is of little instructional value to educators or researchers; a reading deficit of 2 years hardly reflects the same degree of severity for a ninth grader as compared to a third grader. However, the general descriptor of a 2-year deficit provides the initial identifying characteristic to begin an investigation.

The ongoing behavior of reading is comprised of several component processes varying in difficulty. These processes range from simple visual discrimination and recognition of phonemic value, recognition of single word, and apprehension of meaningful word sequence units to sentence comprehension. Fluent readers flow in their processing through meaningful "chunks" of words; disabled readers fail at this process somewhere along the continuum (Benton,

1975). The specific range of difficulties experienced by reading disabled individuals has been nicely summarized by Benton (1975) from descriptions of numerous authors. They generally include the following:

1. Defective graphemic discrimination (relatively uncommon).

2. Improper oral reading of consonants and vowels. Vowels are generally more often misread than initial consonants.

3. Static (i.e., b for d) and kinetic (i.e., saw for was) reversals in reading.

4. Inappropriate word recognition in silent reading, reflecting a defective grasp of major spelling patterns.

5. Omissions and additions of words during oral reading; defects in oral spelling.

6. Word-by-word reading in addition to poor retention of materials read.

Such descriptions inevitably lead to attempts at appropriately identifying reading disabled children for educational intervention. Based on the cluster of identifying characteristics, clinicians have attempted to classify reading disabled children according to various subgroups. A very reasonable classification system has been devised by Boder (1970. 1971, 1973, 1976) which is useful in distinguishing among three major subgroups of disabled readers. The classes include: (a) dysphonetic dyslexics--deficit in grapheme-phoneme

integration and in phonetic analysis and synthesis of words, (b) dyseidetic dyslexics--deficit in perception of letters and words as visual disability, and (c) a combination of the two (from Boder's Diagnostic Screening Test for Developmental Dyslexia).

The utility of such a classification system is in distinguishing among individuals demonstrating auditory associative processing deficit, visual associative processing deficit, and the combination of the two. Performance related identification of sub-groups within reading disabled children suggests the importance of determining the relation of behavior to brain electrophysiological function. The focus of this study is to identify a developmental pattern in brain electrical activity during the performance of several verbal tasks in normal boys, and variations from those patterns among reading disabled boys.

Developmental Considerations and Electrophysiology

The theoretical conceptualization of brain function supporting the preceding hypothesis was developed by Alexander Luria. Based upon nearly 40 years of clinical practice in the examination of brain dysfunction, Luria developed a model of functional organization of the cortex into primary, secondary, and tertiary zones (Luria, 1966). It will suffice for now to explain that cortical processing is dependent upon primary projection areas of sensory input, secondary association areas for generating meaning of the

sensory input, and final multimodal integration in tertiary areas for terminal processing prior to perception of complex information.

The functional organization of the cortex is not a prewired given, but rather a process dependent upon a sequence of myelination and maturation of glial connective tissue. This development is greatly influenced by environment, nutrition, stimulation, and genetic components. As a developmental process, the electrophysiological measurement of maturation in functional organization of cortical process is a logical task. Organization of neural components within the larger system of the brain may be manifested in various expressions of organization of function, because of the facilitative and inhibitory consequences of environmental and genetic variables. The two most significant functions of the fiber system are the inter- and intra-hemispheric inhibition or facilitation of impulse transmission (Seines, 1974). As myelination continues, impulse transmission should be more and more efficient and the underlying neural components of various cognitive functions should become more and more organized as the most efficient mechanisms perform the operation and inhibit other less efficient mechanisms (Kraft, 1983). Further, there is a wide range of cognitive functions that may well be facilitated by a diverse inter-/intra-hemispheric patterning of processes, whereas an inefficiently communicating network will present inhibiting effects

on more appropriate cognitive processing.

Most dramatic in the picture is that the final zones to myelinate are nonspecific association areas of frontal, parietal, and temporal lobes along with inter-/intra-hemispheric association connecting fibers (Flechsig, 1901). Hence, the notion of development of neural substrates to cognitive organization is consistently evident in studies of the progression of myelination in cortical zones and in underlying attentional mechanisms. Reflected in brain electrical activity, the innately determined predisposition for the functional organization of cognitive processing is subject to appropriate progression of myelination. Likewise, the subcortical processing of tonic (reticular activating system) and phasic (thalamic) attentional processes that are subject to the sensitive myelination process are reflected in brain electrical activity as well.

Cognitive processing and the generation of behavior are ongoing functions of the human brain and can be inferred from the analysis of electrical activity recorded from the scalp. The brain/behavior dichotomy can be addressed by looking for relationships between observable behavior and brain electrical activity. Most importantly, the major inference is that by analyzing the patterns in brain electrical activity, mental processes not easily observable can be related to these patterns (Duffy, 1981; Elliot, Halliday, and

Callaway, 1978; Kaye, John, Ahn, and Prichep, 1981; Shucard, McGee, Cummins, Minarick, & Hill, in press). In addition, the human being as a biologic organism is continually developing, and to extend the relationship of electrophysiological function during cognition to the developmental variable is logical and necessary. Thus, the investigation examined normal development and development within a learning disabled group as reflected in a single component of brain electrical activity.

Electroencephalographic (EEG) research is based on the demonstration of functional organization for various types of cognitive processing among areas of the cerebral cortex (Butler & Glass, 1974; Callaway & Harris, 1974; Galin & Ornstein, 1972; Gevins, Zeitlin, and Doyle, 1979a; Rugg & Dickens, 1982; Rugg & Venables, 1980). The procedure differs from clinical electroencephalographic measurement in that subjects are actively engaged in cognitive processing as opposed to relaxed with eyes open or closed. The traditional technique utilized in the collection of electroencephalographic data is based on observation of alpha band (8-12c/sec.) activity as it decreases (alpha blocking) with cognitive processing (Galin & Ornstein, 1972; Gevins et al., 1979a), wherein homologous leads to each hemisphere served to provide indication of relative cortical activation under specific points. The pattern of activation most frequently

subjects performing cognitive tasks was higher alpha activation over the right hemisphere during verbal tasks and more alpha over the left hemisphere during visual-spatial tasks (Galin & Ornstein, 1973).

However, data being analyzed during the last several years demonstrate the relative weakness in the utilization of the alpha blocking technique to infer cognitive activity (Gevins et al., 1979a; Gevins, Zeitlin, Yingling, Doyle, Dedon, Schaffer, Roumasset, and Yeager, 1979b; Gevins, Zeitlin, Doyle, Schaffer, and Calloway, 1979c; Gevins, Doyle, Schaffer, Calloway, and Yeager, 1980; Gevins, 1981; Rugg & Dickens, 1982; Rugg & Venables, 1980). Their data provide support for the utilization of activity in the theta frequency range as one indication of cerebral activity related to relative efficiency of task performance and task engagement (Rugg & Dickens, 1982).

The electrophysiologic organization of cognitive function over normal development and among a differentially identified population of subjects can conceivably be demonstrated utilizing the theta frequency of EEG. The demonstration of organizational development patterns during various cognitive tasks will serve as the basis from which comparison of learning disabled subjects can be made. Such a paradigm would allow for providing additional components to the construction of a model for reading disability. The model would

reflect the increasing functional organization of task engagement as neural maturation selectively inhibits less efficient functional processing (Witelson, 1977a, 1977b). The investigation focused upon delineating differences based upon developmental variables and learning disability variables. Thus, relative differences in the magnitude of theta band spectral intensity collected from association cortex would suggest differences in the physiological substrates of cortical activity.

Present Study

Data from two of the following five protocol tasks: (a) reading comprehension, (b) spelling, (c) Stroop Stimuli, (d) story sequencing, and (e) Mooney Faces (Mooney, 1956), were analyzed in the study. The study included the investigation of the task engagement mechanism in relation to two cognitive tasks which are described as verbal (reading and spelling). It was hypothesized that successful reading behavior is not only dependent upon verbal processing, but is also dependent upon components of visual-spatial processing. Aaron (1982) has summarized the empirical evidence which suggests that reading involves the ability to process verbal stimuli simultaneously as a visual gestalt in addition to the ability to process sequentially. Such data indicate that both cerebral hemispheres would most appropriately be functionally engaged during the performance of reading. Therefore, the theta

band of the EEG spectrum was subjected to analysis in order to test the hypothesis that both hemispheres are equally active and also to assess the occurrence of a task engagement mechanism (after Rugg & Dickens, 1982). In addition, the data were analyzed to determine if a developmental difference could be demonstrated between third- and sixth-grade boys, and how those differences may relate to differences between the normal and learning disabled groups.

Method

Twelve normally-achieving righthanded boys (6 third-grade normal and 6 sixth-grade normal) and 12 reading disabled boys (6 third-grade reading disabled and 6 sixth-grade reading disabled) were included in the study. No family history of sinistrality was found. The boys were given a variety of performance tasks to assess handedness (Oldfield, 1971).

Two verbal tasks were utilized for the investigation. Both tasks were from the Peabody Individual Achievement Test (PIAT)—the reading comprehension and spelling recognition subtests. Items on the reading comprehension subtest require the subject to silently read a sentence and to verbally report the number (1-4) of the picture on the following stimulus card which best represents what was read. Likewise, the spelling task required the subject to correctly select from an array (1-4) of four spellings the stimulus

word given orally by the experimenter. An 80% correct performance criterion was established to assure subjects' appropriate task behavior. Such a criterion indicates the task is of sufficient difficulty to demand appropriate cognitive performance, yet does not present unnecessary difficulty in completion. The PIAT is presented in a standing ring binder which is placed directly in front of the subject while the experimenter controls the pace of advancing each new stimulus card. Subjects are situated within 18 in. (.46 m) of the stimulus items during presentation. They are required to respond to items from each subtest for a 1-minute session for two nonrepetitive administrations of stimulus items during the EEG data collection. Each task was randomly presented within a number of other cognitive tasks, during which EEG was also recorded. Items were selected for administration appropriate to normal third- and sixth-grade performance levels. In addition, items appropriate to the performance levels of the reading disabled boys as indicated by their WISC-R scores were selected. Thus, two one-minute EEG samples were recorded from each subject for each task. The tasks were selected to represent verbal tasks associated with the reading process while enabling control of response requirements (Gevins et al., 1979a).

An Electro-Cap(r) was utilized for electrode placement. Two channels of EEG data were recorded from bilateral electrode sites

P3-T5 and P4-T6, with the left ear serving as the ground. Impedence was maintained below 10K ohms. Master sensitivty was set at 7.5 mv/mm, with high frequency of 70 c/sec. and a time constant of .3 seconds. The signals were recorded on a stereo FM cassette recorder after Vetter FM conversion from the direct signal of the Beckman Accutrace eight-channel EEG. A 1-minute sample of EEG data was collected for each task administration beginning with the onset of task performance. The permanently recorded signal was then available for subsequent analog to digital conversion prior to Fast Fourier Transform (FFT) Power Spectral Analysis.

The data analysis was achieved at The Ohio State University's Hybrid Computer Facility in the Department of Biomedical Engineering. The EEG real-time analog data reduction is accomplished with two hybrid computer programs: the first for sampling 1 minute of data, and the second for processing the real-time data into a frequency histogram for printout. The analysis program samples the data 100 times per second and generates 6,144 data values per minute, following initial digital conversion and storage of the analog signal on the RK05 disk pack. Each FFT window pass covers 2.56 seconds of data, and four passes cover approximately 10.25 seconds (10 seconds). The power histogram results of each FFT pass are averaged in each frequency interval over the four passes and printed out every 10 seconds. The printed

results represent average output at the end of each 10-second data epoch for a total of six epochs. Printout represents power spectral values for each 4c/sec. frequency band (0-40 c/sec.).

Subjects were identified from a local suburban school district with assistance from the school's instructional coordinator. The normal boys were appropriately achieving third- and sixth-graders who demonstrated no history of academic difficulty. Reading disabled boys were identified by their placement in special classes due to performing at least 2 years below their expected level as indicated by the WISC-R. In addition, each learning disabled boy showed at least a 10-point deficit in verbal IQ as compared to performance IQ of the WISC-R. The protocol administration occurred within the school, with the subject and experimenter in one room and the EEG apparatus and technician in another.

Individual subjects had a period of desensitization to the equipment prior to electrode placement. Subjects were taken to an adjoining room and seated at the table where stimuli would be presented. Electrodes were activated and impedance checked. Instructions and samples of each task were provided prior to the data collection. Subjects were instructed, in the forced choice format, to respond to each stimulus item by saying out loud the number which was associated with the appropriate answer (e.g., 1, 2, 3, or 4). Upon each response the next stimulus item was presented.

Each task was administered for at least 1 minute of intense stimulus presentation, during which on-task behavior was constantly maintained. Order of task presentation was counterbalanced across subjects and distributed twice among the other cognitive tasks in an ABAB design.

Fast Fourier Analysis was performed on the entire minute of task performance and reported in 10-second epochs. Statistical analysis for the present investigation was then limited to the first two 10-second data epochs. The recorded raw signal was high pass filtered at .5c/sec. and low pass filtered at 40c/sec. prior to digital conversion. The digital signal was then put through the Fast Fourier program. The intent was to provide an average power spectrum over frequency bands in both epochs for later analysis of variance. Spectral coefficients were then used to calculate average power in the EEG frequency bands (i.e., theta = 4.0-8.0c/sec. approximately). The data was provided for both right and left hemispheres and for the first and second administration of the task. Main effects were tested for differences in the theta level activity between groups, grade levels, and epochs of EEG activity.

Results

Performance scores were recorded to assure subjects were actually engaged in the task being administered. Subjects were provided with stimulus items appropriate to their performance level

as determined by group-administered achievement tests. A criterion level of 80% correct responding was required of subjects to be included in the data analysis. Mean performance on the reading comprehension task was 83.75%, while the mean score for the spelling task was 86.6%. The mean scores and standard deviations comparing reading and spelling scores across subjects suggests similar degree of task difficulty and performance characteristics, with standard deviations of 3.416 on the reading task and 3.742 on the spelling task.

A frequency histogram was constructed for the first two 10-second epochs of each subject as they performed the cognitive tasks. The histogram is printed as a function of time and the reported data (See Tables 1 and 2) represent the arc sine transformation of the percent of total power contained within the theta band (4-8c/sec. approximately), in order to perform the statistical analysis of variance (ANOVA). Separate ANOVAs were done for each task on the theta band EEG data (factors of group, grade, hemisphere, first or second opportunity to perform the task, and EEG epoch).

Insert Table 1 about here

Insert Table 2 about here

The ANOVA comparing the transformed theta power values during the reading task demonstrated several promising results. Main effect differences in theta values were revealed between the normal and reading disabled groups ($F = 34.159$; $df = 1,160$; $p < .001$), and the third- and sixth-grade groups ($F = 15.522$; $df = 1,160$; $p < .001$). Post hoc analysis (Tukey) showed the direction to be that of higher theta values for third graders as compared to sixth graders, and higher values for reading disabled as compared to normal boys. In addition, theta values were higher during the second 10-second epoch of EEG as compared to the first 10-second epoch ($F = 21.928$; $df = 1,160$; $p < .001$).

Likewise, the ANOVA comparing theta values during the spelling task demonstrated a very similar result. Main effect differences in the identical direction were revealed for groups ($F = 18.761$; $df = 1,160$; $p < .001$), grade levels ($F = 9.842$; $df = 1,160$; $p < .005$), and epochs of EEG activity ($F = 17.971$; $df = 1,160$; $p < .001$). Thus, while theta power tends to show a slight decrease as a function of age and a classification as normal, it also shows a significant tendency to increase as a function of task engagement regardless of age or group label. Hemispheric differences in theta activity were not demonstrated in the sample investigated for the present study in either spelling or reading tasks; significant increases were noted in both hemispheres during the second epoch of EEG activity.

Discussion

The data suggest that there exists a developmental component in slow wave activity of the EEG as individuals perform cognitive tasks. In addition, the data support the existence of differences between the normal groups and learning disabled groups which may be attributed to a developmental component in the EEG. When the data are intuitively arranged so as to be what can be considered the most reasonable developmental order (see Graphs 1 and 2), the pattern is dramatically evident. By placing the third-grade learning disabled boys on one extreme and sixth-grade normal boys on the other, it is found that the sixth-grade learning disabled boys and the third-grade normal boys fall between the two extremes. However, sixth-grade learning disabled boys are still behind third-grade normal boys in demonstrating higher power values in the theta band of the EEG. Such a result becomes valuable to interpreting factors related to developmental variables that pertain to the electrophysiological substrates of learning disabilities.

Insert Graph 1 about here

Insert Graph 2 about here

Continued investigation is warranted to continue explicating electrophysiological parameters related to learning disorders. Such information would supplement currently applied methods of interpretive assessment to more clearly describe the functional integrity of an individual's performance characteristics and the physiological mechanisms which underlie them. Clinical applications of these methodologies are currently premature. However, the ongoing investigation of the physiological mechanisms of learning and their relationship to standardized assessment techniques may lead to a much larger and more valuable picture of the entire spectrum in learner characteristics.

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Table 1

Reading Subtest Cell Means

Arc Sine Transformation of Percentage of Raw Theta Power

First Administration

	Epoch 1		Epoch 2		Epoch 1		Epoch 2	
	Mean	S. D.	Mean	S. D.	Mean	S. D.	Mean	S. D.
3 LD	19.5	8.5	21.7	7.9	17.5	6.3	20.8	8.1
3 N	15.8	9.5	21.3	5.1	14.1	8.0	16.2	6.8
6 LD	13.1	4.9	18.9	5.7	13.1	5.7	18.5	7.8
6 N	10.2	1.9	14.2	6.2	10.6	3.1	10.6	5.0
	Left Hemisphere				Right Hemisphere			

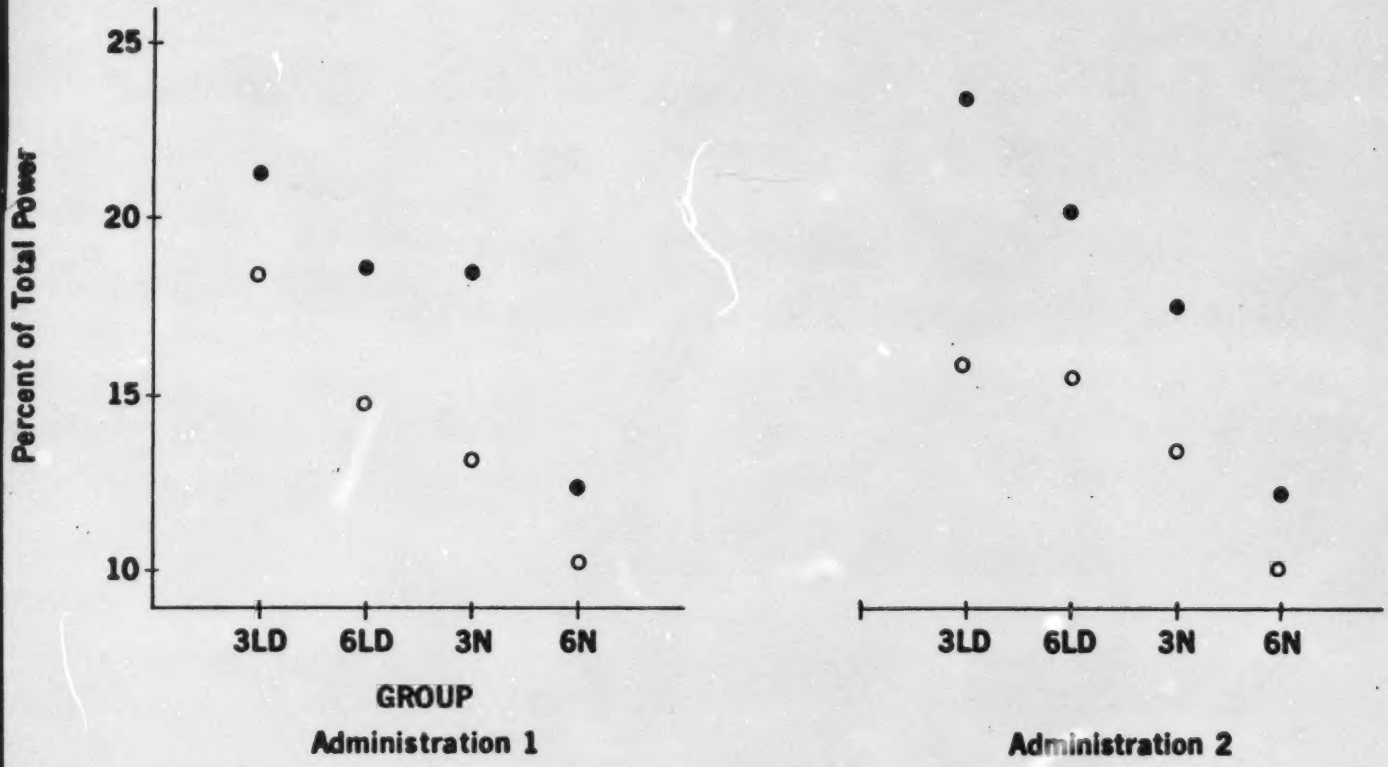
Table 2

Reading Subtest Cell Means

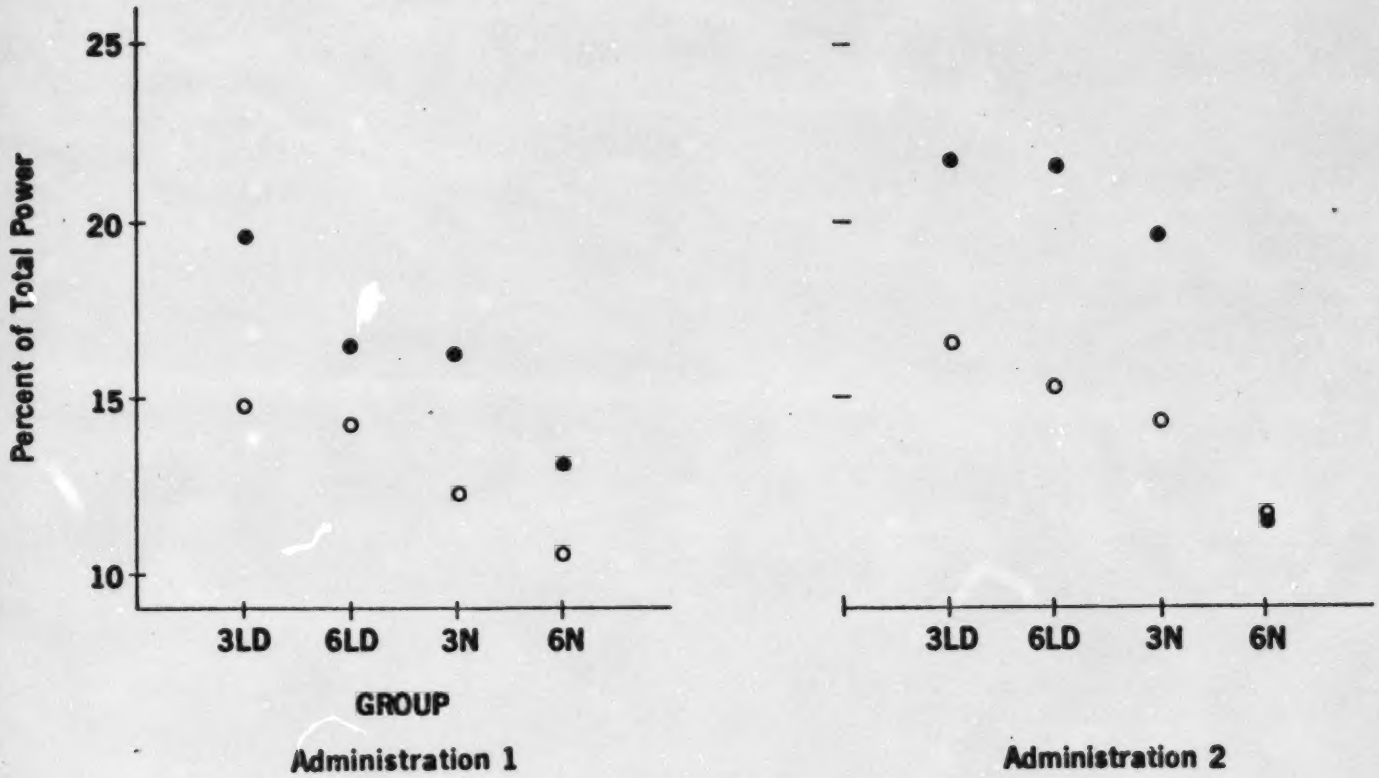
Arc Sine Transformation of Percentage of Raw Theta Power

	Second Administration							
	Epoch 1		Epoch 2		Epoch 1		Epoch 2	
	Mean	S. D.	Mean	S. D.	Mean	S. D.	Mean	S. D.
3 LD	11.3	3.1	22.9	9.0	20.7	6.6	24.3	6.4
3 N	13.9	2.6	20.5	6.0	17.5	5.3	19.9	7.6
6 LD	11.6	3.0	19.3	3.8	15.4	4.7	15.9	7.5
6 N	9.8	2.9	11.3	4.1	10.4	4.3	13.4	5.4
	Left Hemisphere				Right Hemisphere			

Reading Subtest Cell Means (arc-sin transform) of Raw Theta Power Percentage of Total, Collapsed Over Hemispheres.



Spelling Subtest D Cell Means (arc-sin transform) of Raw Theta Powe
Percentage of Total, Collapsed over Hemispheres.



○ epoch 1
● epoch 2
n=48

LD: Learning Disabled
N: Normal